Chroma Meter Calibration: Optimizing CMF Accuracy for Realistic Lighting Situations

Abstract

The RGB Evaluation Kit is designed to evaluate the performance of the RGB sensor. The kit is accompanied by a graphical user interface (GUI) that contains the CIE 1931 Chromaticity diagram with Planckian locus in an x, y- coordinate system, with cross marks to point out where the RGB sensor position is on the graph. The GUI facilitates evaluation of parameters such as raw data of Red, Green and Blue as well as X, Y and Z corrected lux measurements and also performs interrupt functions. Data can be viewed on the GUI and/or saved to a text file for future analysis. The GUI software is compatible with Windows XP®, Windows Vista®, and Windows® 7. This provides a simple user interface for exercising the device features.

The system (MCU, DUT) is powered directly from the universal serial bus (USB) or from a single-supply voltage of 2.25V to 3.6V. The evaluation board must be connected to a computer through the mini USB port for the system to function. The system uses a USB MCU to communicate to the DUT via I^2C/SMBus interface.

FIGURE 1. EVALUATION BOARD

Reference Documents

RGB Chroma Meter Setup

Standard Illuminants

Chromaticity

Color temperature

Planckian locus

Colour & Vision Research laboratory

Mired

CIELUV

Least Squares

Linear Regression

CIE 1960 Color Space (MacAdam - uv)

Wratten Number

Evaluation Hardware/Software User Manual for RGB Sensor

Evaluation Package (Online Order)

The package consists of the hardware, software, and documentation listed in the following:

- User Guide (Online)
- Product Datasheet (Online)
- Presentation (Installer File)
- uv-xy table (Installer File)
- CCM Calibration Worksheet (Installer File)
- User Guide (Installer File)

Hardware Requirements

- mini USB cable
- Evaluation Board

Installation of the Graphical User Interface (GUI) Software and USB Driver

Download the software from the link provided in the “Reference Documents” section. Once the application is downloaded from the website, double-click the file to start installing the GUI. The user will be greeted by the screen shown in Figure 2. Continue through the installer and read the instructions. Figures 2 through 6 show the complete installation process.

The USB Evaluation Board should always be connected via the USB until the installation has been satisfactorily completed.

Background

Body

CMF Functions

The equipment used is shown in Figure 2.

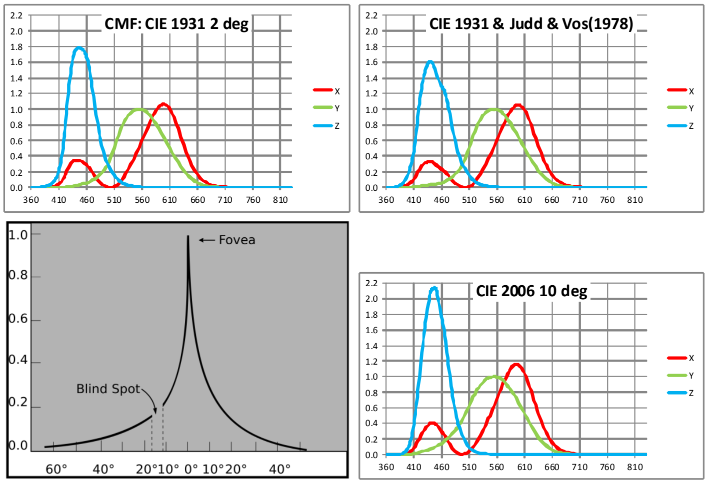


FIGURE 2. CMF Functions
From: [Wikipedia: Fovea centralis](#)
[Colour & Vision Research Laboratory](#)

Color Space

blah

The equipment used is shown in Figure 3.

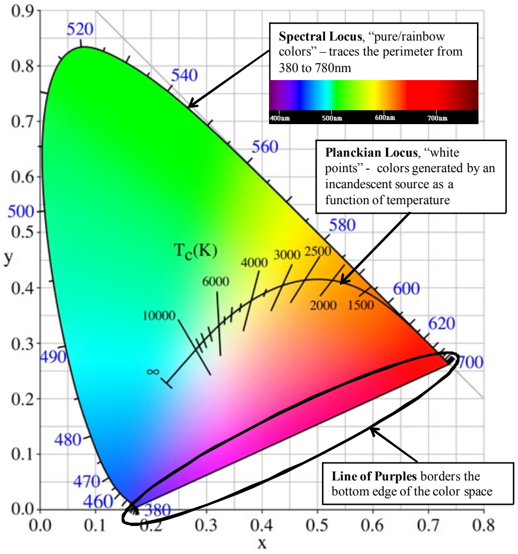


FIGURE 3. 1931 CIE Chromaticity Space
From: [Wikipedia: Color Temperature](#)

The equipment used is shown in Equation 1.

$$X = \int_{380}^{780} I(\lambda)\,\overline{x}(\lambda)\,d\lambda \qquad x = \frac{X}{X+Y+Z}$$

$$Y = \int_{380}^{780} I(\lambda)\,\overline{y}(\lambda)\,d\lambda \qquad y = \frac{Y}{X+Y+Z}$$

$$Z = \int_{380}^{780} I(\lambda)\,\overline{z}(\lambda)\,d\lambda \qquad z = \frac{Z}{X+Y+Z}$$

Black Body Spectral Power Distribution:

$$I(\lambda, T) = \frac{2hc^2}{\lambda^5}\frac{1}{\exp\left(\frac{hc/\lambda}{kT}\right) - 1}$$

(EQ. 1) XYZ → xy conversion
From: [Wikipedia: Planckian locus](#)

The equipment used is shown in Figure 4.

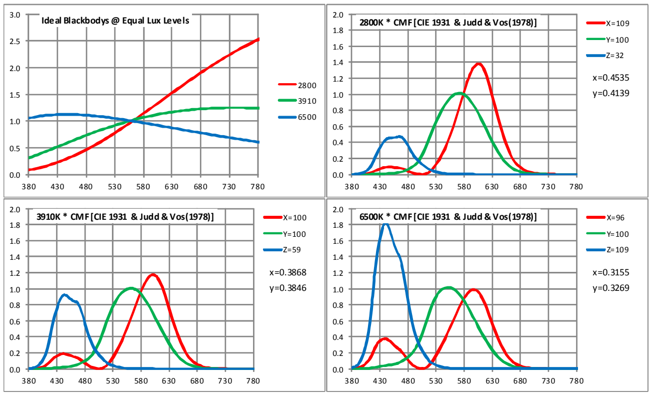


FIGURE 4. Black Body - CMF Product

1960 UCS

The equipment used is shown in Figure 5.

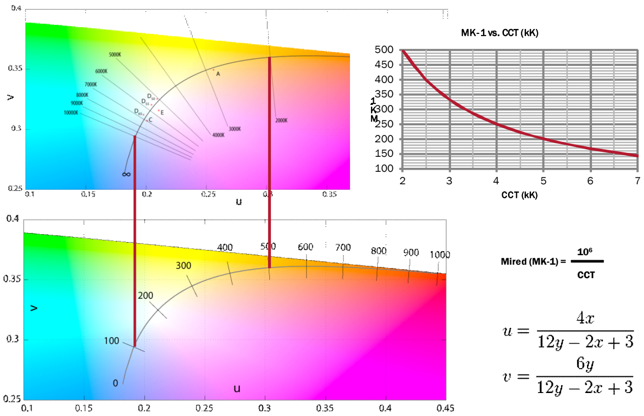


FIGURE 5. 1960 UCS
From: [Wikipedia: CIE 1960 color space](#)
[Wikipedia: Mired](#)

The equipment used is shown in Equation 2.

$$\bar{u}(T) = \frac{0.860117757 + 1.54118254 \times 10^{-4} T + 1.28641212 \times 10^{-7} T^2}{1 + 8.42420235 \times 10^{-4} T + 7.08145163 \times 10^{-7} T^2}$$

$$\bar{v}(T) = \frac{0.317398726 + 4.22806245 \times 10^{-5} T + 4.20481691 \times 10^{-8} T^2}{1 - 2.89741816 \times 10^{-5} T + 1.61456053 \times 10^{-7} T^2}$$

(EQ. 2) Planckian Locus Approximation - 1960 UCS
From: Wikipedia: Planckian locus

Color Correction Matrix

A color correction matrix, CCM, is a transform used to adjust for system aberrations which cause for non-ideal performance. In our case we use a first order CCM to attempt to match the detected RGB values to a predefined color matching function, CMF. The definition of a first oder CCM is given in Figure 6. The

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} \begin{vmatrix} C_{RX} & C_{GX} & C_{BX} \\ C_{RY} & C_{GY} & C_{BY} \\ C_{RZ} & C_{GZ} & C_{BZ} \end{vmatrix} \begin{vmatrix} R \\ G \\ B \end{vmatrix} \Rightarrow \begin{aligned} X &= C_{RX}R_E + C_{GX}G + C_{BX}B \\ Y &= C_{RY}R + C_{GY}G + C_{BY}B \\ Z &= C_{RZ}R + C_{GZ}G + C_{BZ}B \end{aligned}$$

FIGURE 6. CCM definition

matrix shown on the left hand side of the figure represents the three equations on the right hand side of the figure.

SPECTRAL LOCUS BASED CCM DERIVATION.

The Spectral Locus, as represented in the CIE 1931 Color Space, is the top outer boundary of “pure colors” consisting of monochromatic light. This is shown in Figure 7.

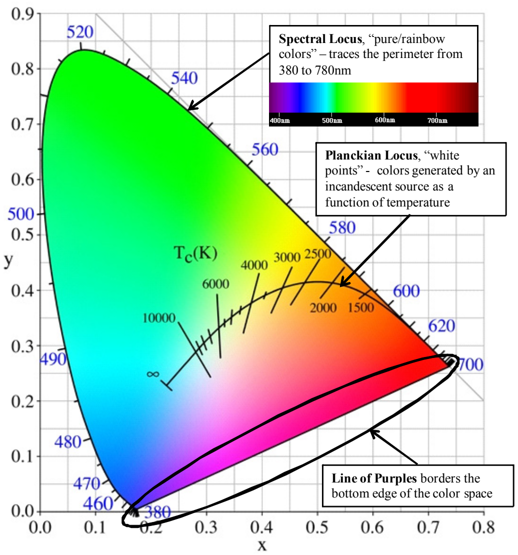


FIGURE 7. 1931 CIE Chromaticity Space
From: [Wikipedia: Color Temperature]

The spectral response of the RGB device can be used to calculate a CCM which best matches the Spectral Locus. The pre and post corrected response curves are shown in Figure 8. The top graph

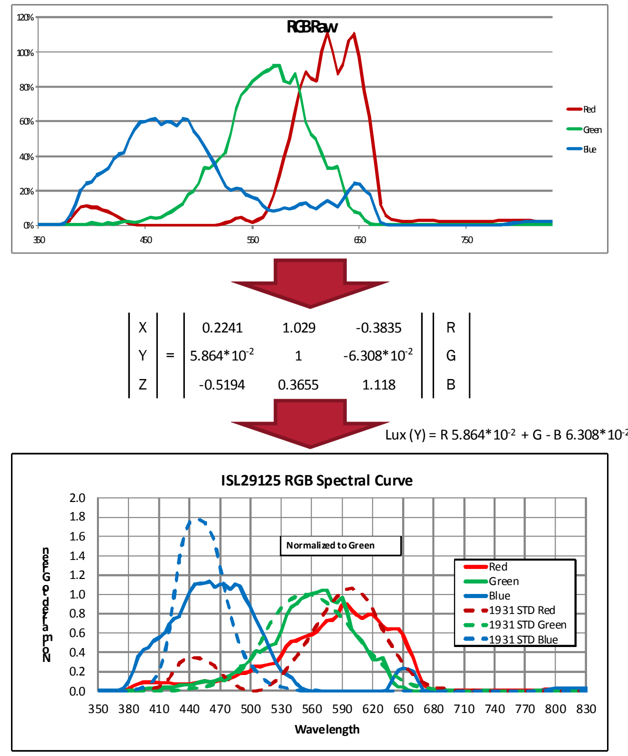


FIGURE 8. Color Corrected RGB Spectra

shows the raw response curve of the RBG sensor. The bottom curves show the corrected response curve after the application of the CCM and the reference CMFs. Between the curves are the CCM coefficients & an explicit definition of the Y (Lux) term expressed as a function of RGB values. The CCM was calculated using a **[Linear Regression]** on a set of data points ranging from λ=350 to 830nm. If we retrace the resultant XYZ curve on the chromaticity chart (Figure 9) the region of operation is defined

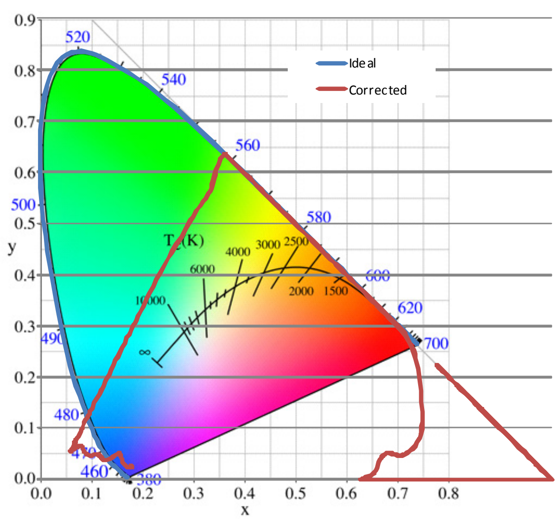


FIGURE 9. CMF vs. RGB corrected spectral locus trace

within the curve.

Setup

The equipment used is shown in Figure 10.

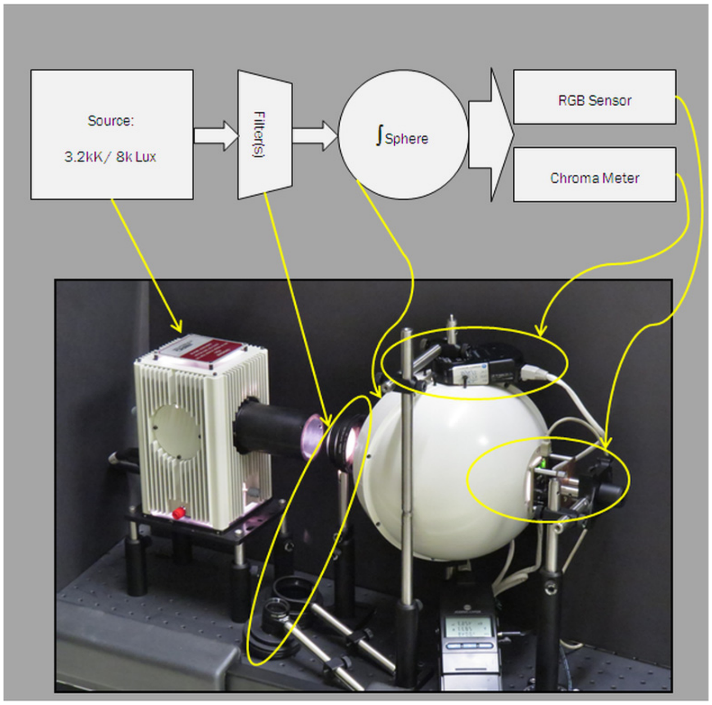
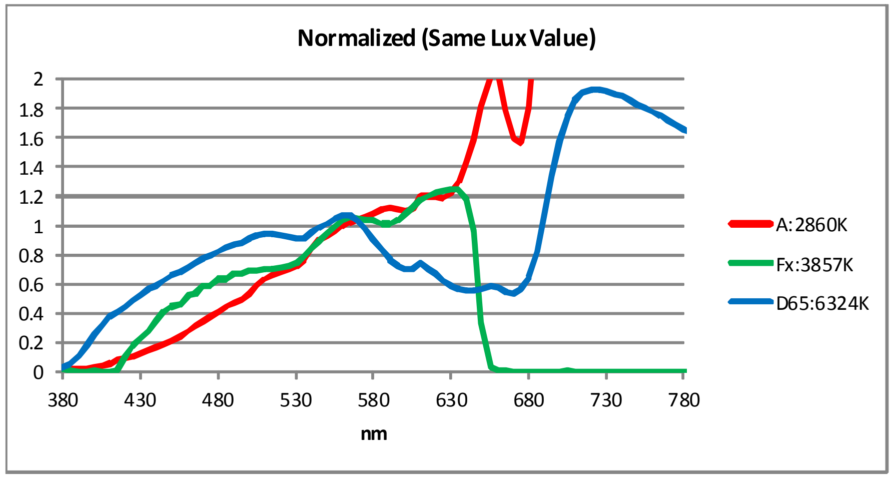


FIGURE 10. Optics2 Configuration

Sources

We wish to calibrate the device with values representative of the range of lighting the sensor is likely to see. The spectra of the 3 filters chosen are shown in Figure 11.



	Desired		Filter Characteristics					Measured	
	CCT	MK-1	Filter	LB(MK-1)	CC	OD (Vis)	Stops	CCT	Lux
Source								~3200K	~8000
A	2800	357	81EF	52		0.2	2/3	2860	515
			ND			1.2	4		
"CWF"	3914	255	KB6 (81EF)	52		0.2	2/3	3860	1210
			15M		15M	0.1	1/3		
			ND			0.3	1		
			SP650NM		15G?				
D65	6500	154	80B	-112		0.5	1 2/3	6320	580
			82B (2x)	-32		0.2	2/3		
			ND			0.6	2		

FIGURE 11. Calibration Light Sources
From: Sekonic C-500 Manual
BH Photo Camera Filters

DUT Mechanics

Details of some of the important aspects of the evaluation board are shown in Figure 12.

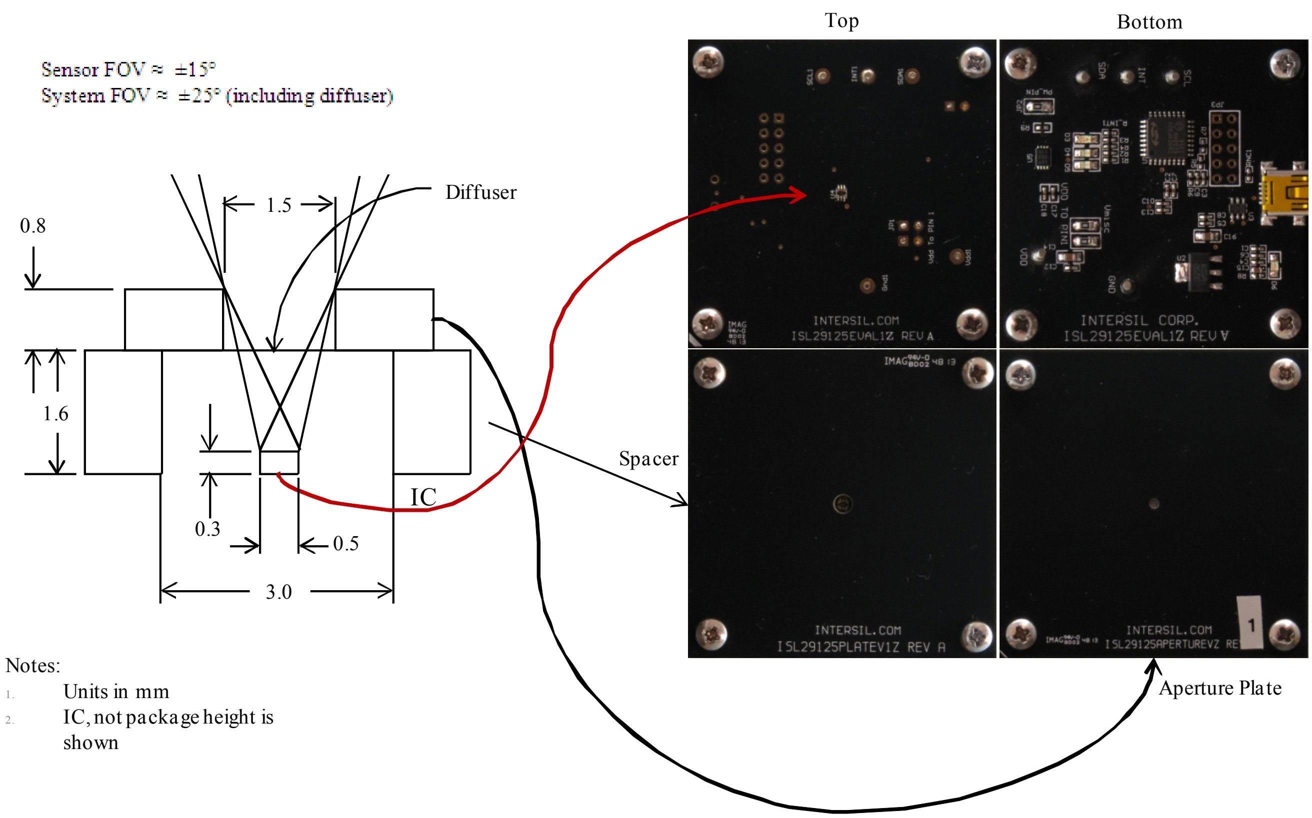


FIGURE 12. DUT Diffuser & Aperture

Measurements / Calculations

Blah blah

Application of Calibrated Results

It is useful to separate the gain value from the CCM, with the CCM normalized to 1 for the GY coefficient. A single light source with a couple of measurements can be used efficiently in production to do a final adjustment to enhance system accuracy by adjusting only this term. For the convenience of driver implementation the units chosen for this term is LSBs/Lux (relative to the Green/Y channel). Three values effect the calculation of this term, the nominal FS of the range selected, the FS code of the resolution selected, and the system gain measured during system characterization. An example of these values is shown in Figure 13.

BITS	RNG	FS Lux	FS Code	Sys Gain	G LSBs/Lux
0	0	375	65535	3.5297	49.5112
0	1	10250	65535	3.4605	1.8476
1	0	375	4095	3.5297	3.0937
1	1	10250	4095	3.4605	0.1154

FIGURE 13. System Gain Results

The system gain term is a combination of the sensor, its FOV (field of view), and any attenuation from covering optics. The actual value of G from the table is determined by the selection of the range (RNG) and resolution (BITS). Note that with this example the system gain value of approximately 3.5 increases the full-scale of the lower range to about 1.3k Lux a level beyond where a typical LED or LCD panel has normally be adjusted to full brightness. The actual full-scale of the sensor as defined by none of the channels saturating will also be color temperature dependent. Low color temperature lighting, such a with an A illuminate, will cause the red channel to saturate first. High color temperature, such as a D65 illuminate with cause the blue channel to saturate first.

For the purposes of auto ranging switching to the higher range when >1k Lux is detected and switching to the lower range when <900 Lux is detected would provide the sensor with plenty of headroom for the low range for color temperature variations while the 100 Lux hysteresis would keep the sensor from constantly switching ranges.

In Figure 14 all of the calibration terms are shown. For maximum performance two range dependent CCMs are shown. Note that

Gain (**G**)		Nominal FS	System Gain	Resolution (**BITS**) 0	1
				65535	4095
Range (**RNG**)	0	375	3.5297	49.5112	3.0937
	1	10250	3.4605	1.8476	0.1154

CCM: RNG=0		
0.0951	1.0581	-0.5557
0.0345	1	-0.3874
-0.2971	0.0404	0.9062

CCM: RNG=1		
0.0871	1.0588	-0.5376
0.0240	1	-0.3652
-0.3150	0.0332	0.9436

C_{RX}	C_{GX}	C_{BX}
C_{RY}	C_{GY}	C_{BY}
C_{RZ}	C_{GZ}	C_{BZ}

$$X = (C_{RX}R_{CODE} + C_{GX}G_{CODE} + C_{BX}B_{CODE}) / G$$
$$Y = (C_{RY}R_{CODE} + C_{GY}G_{CODE} + C_{BY}B_{CODE}) / G$$
$$Z = (C_{RZ}R_{CODE} + C_{GZ}G_{CODE} + C_{BZ}B_{CODE}) / G$$

Lux (Y) $= (0.0345R_{CODE} + G_{CODE} - 0.3874B_{CODE}) / 49.5112$: Range=LO (375), Resolution=16bit

FIGURE 14. Results with Combined Terms

difference in individual terms are minimal. A single CCM, averaging the two together could also be used to simplify the driver code. The Lux term (Y) is shown at the bottom. This example uses the calibration terms from the low range with 16 bit resolution. In this example the resolution of the sensor is about 20mLux.

Performance

In this section we will show the typical performance you can expect after performing the calibration procedure outlined in this document.

References